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REPORT OF INVESTIGATIONS/1990

Laboratory Testing of the CSE SR-100 Self-Contained Self-Rescuer for Ruggedness and Reliability

By Nicholas Kyriazi, John Kovac, Wayne Duerr, and John Shubilla

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UNITED STATES DEPARTMENT OF THE INTERIOR

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Library of Congress Cataloging in Publication Data:

Laboratory testing of the CSE SR-100 self-contained self-rescuer for ruggedness and reliability / by Nicholas Kyriazi ... [et al.].

p. cm. — (Report of investigations; 9328)

Includes bibliographical references (p. 11).

Supt. of Docs. no.: I 28.23:9328.

1. Self-contained self-rescuer (Mine rescue equipment)—Reliability. 2. Coal mines and mining—Safety measures. I. Kyriazi, Nicholas. II. Series: Report of investigations (United States. Bureau of Mines); 9328.

TN23.U42 [TN297] 622 s—dc20 [622'.89] 90-2480 CIP

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	L/min	liter per minute
g	acceleration due to gravity	m	meter
h	hour	min	minute
Hz	Hertz	mm Hg	millimeter of mercury (atmospheric pressure)
kg	kilogram	s	second
L	liter	yr	year

LABORATORY TESTING OF THE CSE SR-100 SELF-CONTAINED SELF-RESCUER FOR RUGGEDNESS AND RELIABILITY

By Nicholas Kyriazi,[1] John Kovac,[2] Wayne Duerr,[3] and John Shubilla[4]

ABSTRACT

The U.S. Bureau of Mines subjected the CSE SR-100 self-contained self-rescuer (SCSR) approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) to a series of laboratory treatments designed to simulate various environmental conditions in underground coal mines. The tests were designed to predict the ability of the self-rescuers to withstand those environmental stresses without causing a decrease in wearer protection. The apparatus were heated to 71° C for 48 h, cooled to -45° C for 16 h, vibrated for 9 h, and dropped 1 m on each axis. A critical concern was internal damage to an apparatus, without any obvious external signs, that would cause it to malfunction or seriously degrade its performance.

Carbon dioxide (CO_2) levels in apparatus with combined treatments were higher than in apparatus with individual treatments and untreated apparatus. The higher levels remained within safe limits, however. None of the treatments caused venting of the small oxygen cylinder that provides starter oxygen. Some bottles were found to be empty because of manufacturing defects in the burst disks. This problem was corrected in later models. The heat treatments did make the case ends more difficult to remove and the breathing bag sticky and subsequently more difficult to unfold. An apparatus that was dropped and vibrated had a broken desiccant bag that released some of its contents which compromised the seal of the relief valve. The case was dented from the drops. As with the first-generation self-rescuers, if there is visible damage to the case of the apparatus, the apparatus should be considered to be internally damaged and must be removed from service.

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INTRODUCTION

On June 21, 1981, coal mine operators in the United States were required to make a 1-h, NIOSH and MSHA-approved, SCSR available to each person entering an underground coal mine. The regulations (30 CFR 75.1714) require that each person in an underground coal mine wear, carry, or have immediate access to, an SCSR that provides an oxygen source. The SCSR's deployed in 1981 and 1982 are large and heavy compared with the filter self-rescuers (FSR's) presently belt worn. The FSR's protect only against low levels of CO, but since they are so much lighter and smaller than the SCSR's, the FSR's continue to be worn on the belt while the SCSR's are largely stored. The CSE SR-100 was designed to be able to be belt worn.

The SCSR's deployed in 1981 and 1982 underwent the U.S. Bureau of Mines testing for mine worthiness in programs begun in late 1980 (*1-2*).[5] There is no implication that either NIOSH, MSHA, or the manufacturers have conducted less than thorough testing of these devices. However, the gradual deterioration that all equipment and materials undergo necessitates a study of environmental effects, which can help in the estimation of equipment lifetime. The rate of deterioration will certainly vary depending upon use: apparatus that are stored in a benign environment will fare better than those that are mounted on vibrating machinery or those that are worn or carried in and out of the mine every day.

Experience with the first-generation SCSR's, those deployed in 1981 and 1982, gained from the Bureau's long-term field evaluation, has shown no problems in the areas investigated. Problems were experienced instead with manufacturing defects and poor training in both inspection of the SCSR's for damage and in donning procedure.

Until actual field experience is available for the SR-100, the laboratory tests offer the following benefits: (1) If the test is severe enough, one can directly observe the failure mode for a particular environmental stressor on the equipment, and (2) the laboratory test results can be used as indicators of areas where attention should be focused during the field evaluation.

Of major concern are situations where the unit exhibits no external damage, but where internal damage has occurred that markedly degrades the performance of the apparatus and possibly makes it inoperable. Obvious external damage, which mandates removal from service and refurbishment, is of no concern from a safety viewpoint, but is reported for informational purposes.

ACKNOWLEDGMENTS

The authors thank Henry Kellner, industrial engineering technician, Richard Unger, civil engineer, and Sean Gallagher, research psychologist, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA, for their participation in the treadmill testing in this study.

DESCRIPTION OF APPARATUS

In general, a closed-circuit, self-contained breathing apparatus of any type consists of (1) a mouthpiece or facepiece, and breathing hoses, (2) an oxygen source, (3) a CO_2 absorbent, and (4) a breathing bag. The SR-100 is a pendulum-type apparatus, utilizing a bidirectional flow path with no check valves (figs. 1-2). It is a chemical-oxygen system of unusual design with a chemical bed containing both potassium superoxide (KO_2) and lithium hydroxide (LiOH). KO_2 both absorbs CO_2 and produces oxygen, while LiOH absorbs CO_2 only. Pure KO_2-bed apparatus produce approximately twice as much oxygen as they can absorb CO_2 produced by the wearer. As a result, the beds are oversized with regard to oxygen production in order to absorb adequately the user's CO_2. The addition of LiOH to the bed balances this characteristic somewhat. In addition, hygroscopic materials are used in a saliva trap in the breathing hose and in the breathing bag to prevent moisture from overreacting the KO_2 in the bed. These features enable the SR-100 to be much smaller and lighter than pure-KO_2 apparatus for the same amount of usable oxygen.

Since the release of oxygen resulting from the reaction of the exhaled CO_2 and moisture with the KO_2 is not

[5] Italic numbers in parentheses refer to items in the list of references at the end of this report.

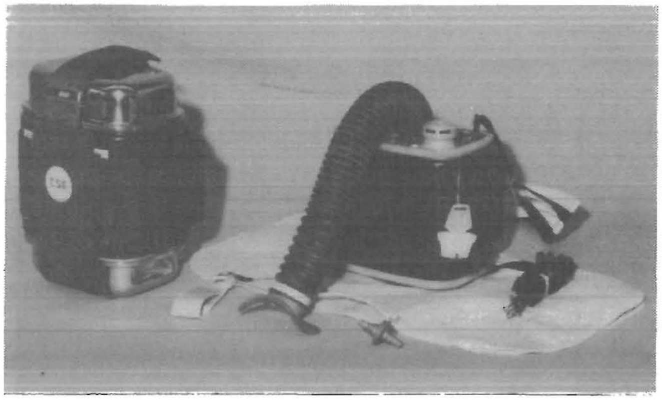

Figure 1.—Cased (left) and uncased (right) SR-100 self-rescuer.

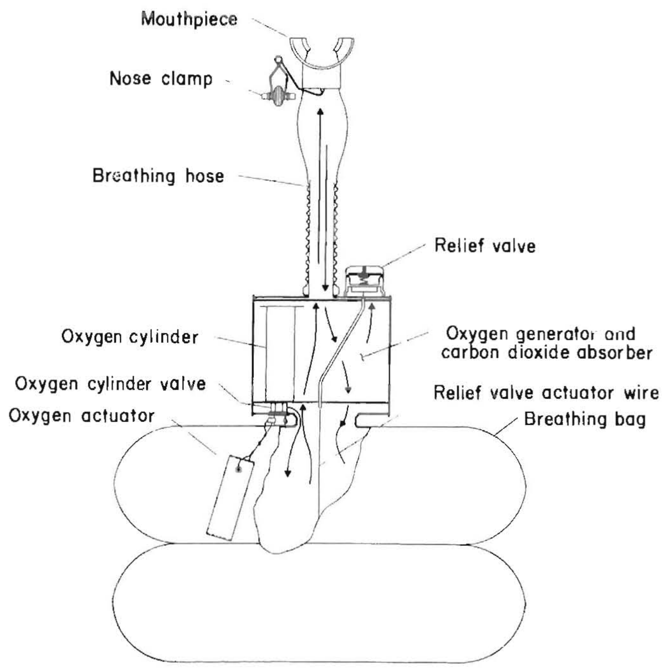

Figure 2.—Schematic of SR-100 self-rescuer.

instantaneous, a small, compressed-oxygen cylinder provides approximately 9 L of starter oxygen. This bag full of oxygen carries the user through the chemical bed start-up period.

A volume-activated relief valve vents some of the breathing gas when the breathing bag becomes full, dumping high-CO_2 air at a point just above the chemical bed.

EXPERIMENTAL DESIGN AND TEST METHODS

Laboratory testing consisted of first environmentally treating the SCSR's and then measuring the effects of the treatments on operational performance. The treatments applied were temperature extremes (71° C for 48 h (*3*) and -45° C for 16 h) and shock and vibration. The shocked and vibrated apparatus were also heated and cooled to check for combined effects. In addition, one apparatus was subjected to 100° C for 4 h. Human-subject tests on a treadmill (fig. 3) and machine tests using a breathing and metabolic simulator (BMS) (fig. 4) were used to measure the effects of the environmental treatments on SCSR performance. Human-subject testing provided relevant human-factor information; the BMS tests provided a more reproducible method for quantifying the duration of respiratory protection and performance parameters. The Bureau's most recently acquired BMS was used for this program (*4*).

The workload for both the BMS and treadmill tests was a moderate one with an oxygen consumption rate of 1.35 L/min STPD (standard temperature and pressure, dry: 0° C, 760 mm Hg). This work rate represented the average work rate that would be exhibited by a 50th-percentile miner (87 kg) performing a 60-min man-test 4, as described in 30 CFR 11H (*5*).

For a treatment to be considered to have had no impact on an apparatus, there must be no significant degradation in the various measured parameters compared with the control tests.

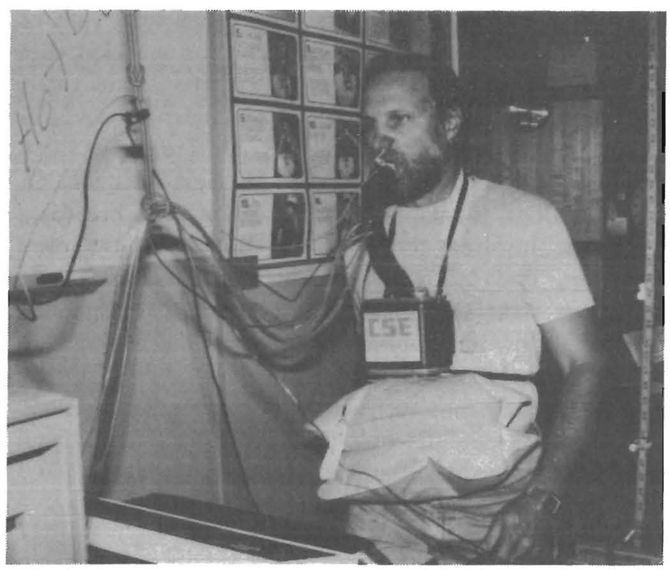

Figure 3.—Treadmill testing of SR-100 self-rescuer.

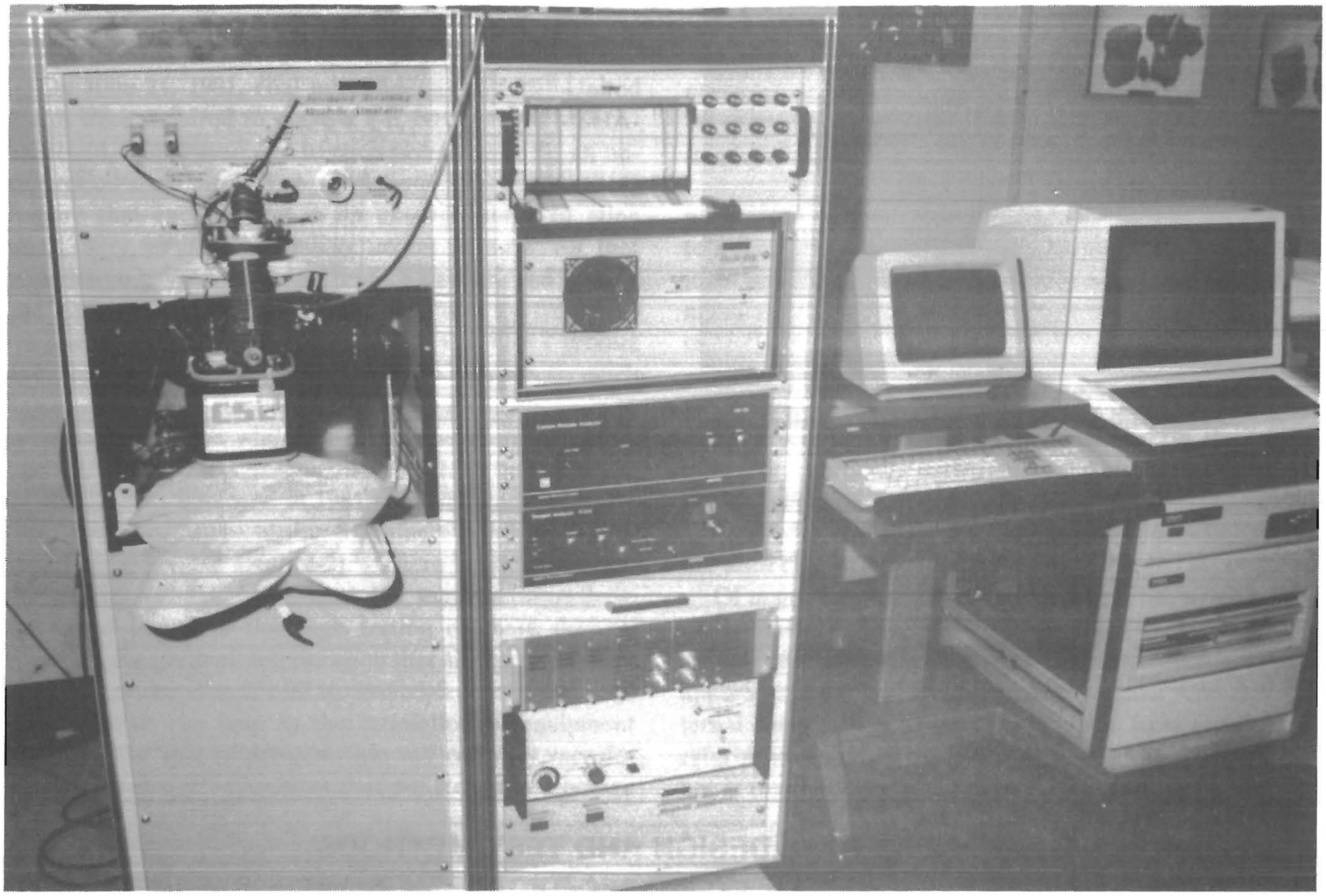

Figure 4.—Breathing and metabolic simulator testing of SR-100 self-rescuer.

TREADMILL TESTING

Three human test subjects were used. They were run at speeds that elicited an oxygen consumption rate of 1.35 L/min STPD. With a fixed oxygen consumption rate, however, their CO_2 production rates, ventilation rates, and respiratory frequencies cannot be controlled and differed from each other and the BMS. Differences in these parameters will cause differences in their inhaled CO_2 concentrations, inhalation and exhalation peak breathing pressures, inspired temperatures, and, possibly, even durations. The tests were terminated when the user could no longer wear the apparatus; in these tests, that was because of low bag volume, insufficient to accommodate an entire inhalation.

Continuously monitored were oxygen and CO_2 levels, inhalation wet- and dry-bulb temperature levels, and both inhalation and exhalation peak breathing pressures.

BMS TESTING

The metabolic parameters used in BMS testing are, all volumes at STPD:

Oxygen consumption rate . .	1.35 L/min
CO_2 production rate	1.10 L/min
Ventilation rate	30.0 L/min
Respiratory frequency	18 breaths/min

The tests were terminated, as with the treadmill tests, when there was insufficient volume in the breathing bag to accommodate an entire inhalation.

Continuously monitored were average inhaled levels of oxygen and CO_2 (including the effect of dead space), minimum inhaled CO_2 level, inhalation wet- and dry-bulb temperatures, and both inhalation and exhalation peak breathing pressures.

SHOCK AND VIBRATION TREATMENT

There is no specific NIOSH or MSHA requirement in the Code of Federal Regulations for shock or vibration testing of breathing apparatus. Currently, however, NIOSH requires that self-rescuers survive 40 h of shock and vibration on a RO-TAP[6] sieve shaker. The SR-100

[6]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

has successfully passed this test during NIOSH-MSHA approval testing.

The RO-TAP machine subjects the SCSR's to vibration from rotary motion and impacts from hammer blows (2.5 impacts/s). The SCSR is rigidly mounted to avoid excessive acceleration levels to within 15 g's, peak to peak, for the entire test period. The test originated from experience with FSR's and simulates the extent of damage suffered in worst-case tests of harsh mining environments, as well as carrying and mounting on machines for 1 yr. The RO-TAP test itself, however, does not simulate vibration spectra and types likely to be seen on mining machinery. To resolve this problem, a composite test was devised based on the reported vibration levels experienced on portable equipment, on underground mining machines (longwall, continuous) measured on the frame, and on underground and surface haulage vehicles (*6*).

A shaker table of the type used in military standard (MIL-STD) vibration tests was used in the vibration treatment with motion along the vertical (Z) axis only (fig. 5). The test conditions were as follows:

Frequency, Hz	*Acceleration, g (±peak)*
5- 92	2.5
92- 500	3.5
500-2,000	1.5

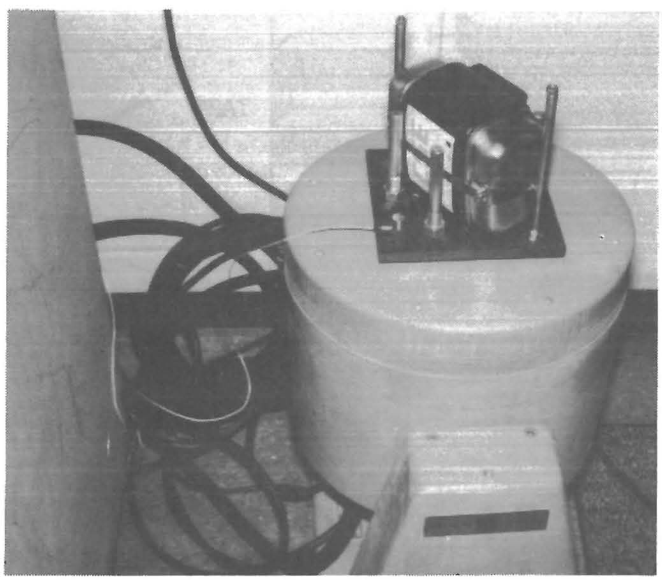

Figure 5.—Vibration table treatment of SR-100 self-rescuer.

There is no consensus as to what constitutes an appropriate vibration treatment simulating the mining environment. MIL-STD-810B, which specifies a frequency range of 9 to 500 Hz at an acceleration of 4 g (± peak), has been recommended (*7*), but others recommend MIL-STD-810C[7] which specifies 1.5 g (± peak) from 5.5 to 30 Hz, increasing to 4.2 g (± peak) at 30 to 500 Hz, as being a more appropriate test.

One procedural variation in this study on the vibration tests was to vibrate the SCSR's unencumbered rather than to strap them down as is usually done. When deployed on machines, it is believed that the SCSR's will not be strapped down tightly, but will be simply placed in unpadded holders if not just thrown on the floor or other surface, unrestrained. Their lateral motion was restricted with pegs screwed onto the vibration table. Although at first inspection, it would seem that the bouncing of the apparatus at lower frequencies would make individual treatments vastly different in vibration and shock insult, the authors believe that the cumulative effect of the unclamped-apparatus vibration treatment over an entire test is similar and reproducible.

The control accelerometer was screw-mounted to the table outside of the range of motion of the SCSR. The frequency range was swept every 20 min for 3 h. The procedure was performed for each axis for a total vibration test duration of 9 h.

For the shock portion of the treatment (drop test), the SCSR was dropped 1 m (belt height) onto a concrete surface. This was performed once on each axis, plus once on a corner.

HIGH-TEMPERATURE TREATMENT

71° C for 48 h.—This treatment was conducted according to procedures described in MIL-STD-810C (*3*), except that the convection oven was preheated.

100° C for 4 h.—This treatment was performed to view the failure mode at high temperature and is not considered to be a condition likely experienced in the field.

LOW-TEMPERATURE TREATMENT

-45° C for 16 h.—This temperature was arbitrarily chosen to be a worst-case condition.

[7]Contract H0155113, Bolt Beranek and Newman, Inc., Jan. 1979.

RESULTS AND DISCUSSION

The results are displayed as bar charts showing how the apparatus performed with regard to duration, average inhaled CO_2 and oxygen, inhaled wet- and dry-bulb temperatures, and inhalation and exhalation peak pressures, for both the BMS and treadmill tests (figs. 6-10). The bars show the averages and standard deviations of five tests on the BMS and two individual tests with human subjects for each of the treatments. The bar lengths for each performance category are the full-duration averages.

BASELINE (CONTROL) TESTS

It was found that there were large differences in the performances of the apparatus worn by the human test subjects. This is attributed mostly to physiological differences. For example, for the same oxygen consumption rate, 1.35 L/min, the ventilation rate of one test subject was approximately 30 L/min with a respiratory frequency of between 25 to 35 breaths/min, whereas another test subject had a ventilation rate of approximately 18 L/min with a respiratory frequency of approximately 10 breaths/min. Higher ventilation rates cause higher peak pressures. Otherwise, however, it is not now known what effects these differences have on the remaining performance measures. This makes it more difficult to distinguish effects caused by the treatments.

HIGH-TEMPERATURE TREATMENT

The case tops and bottoms of heated units were more difficult to remove than those of unheated units. The folded breathing bags were stuck together and required conscientious unfolding.

The one apparatus heated to 100° C retained the oxygen in its starter bottle and performed on the BMS with no problems.

LOW-TEMPERATURE TREATMENT

No problems were experienced with any of the apparatus subjected to the low-temperatures.

COMBINED TREATMENTS

The combined treatments encompassed heating, cooling, and drop and vibration. No drop and vibration treatment was performed exclusively. Higher CO_2 levels were

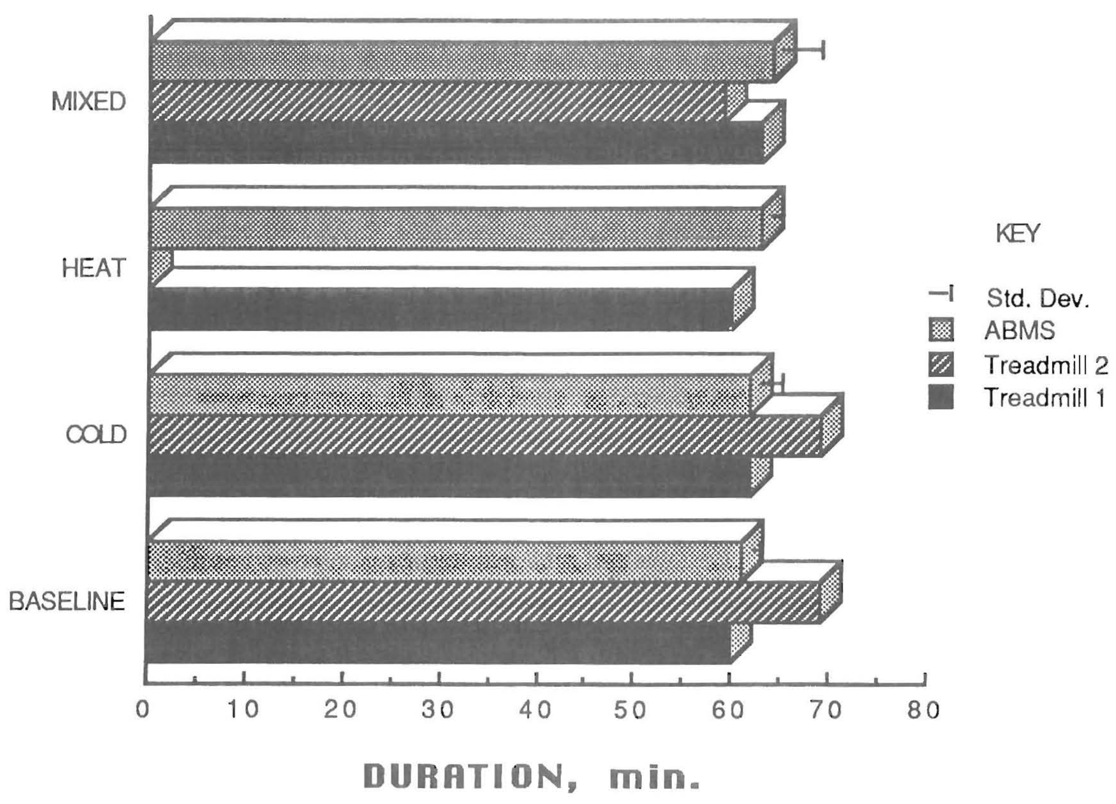

Figure 6.—Performance test durations.

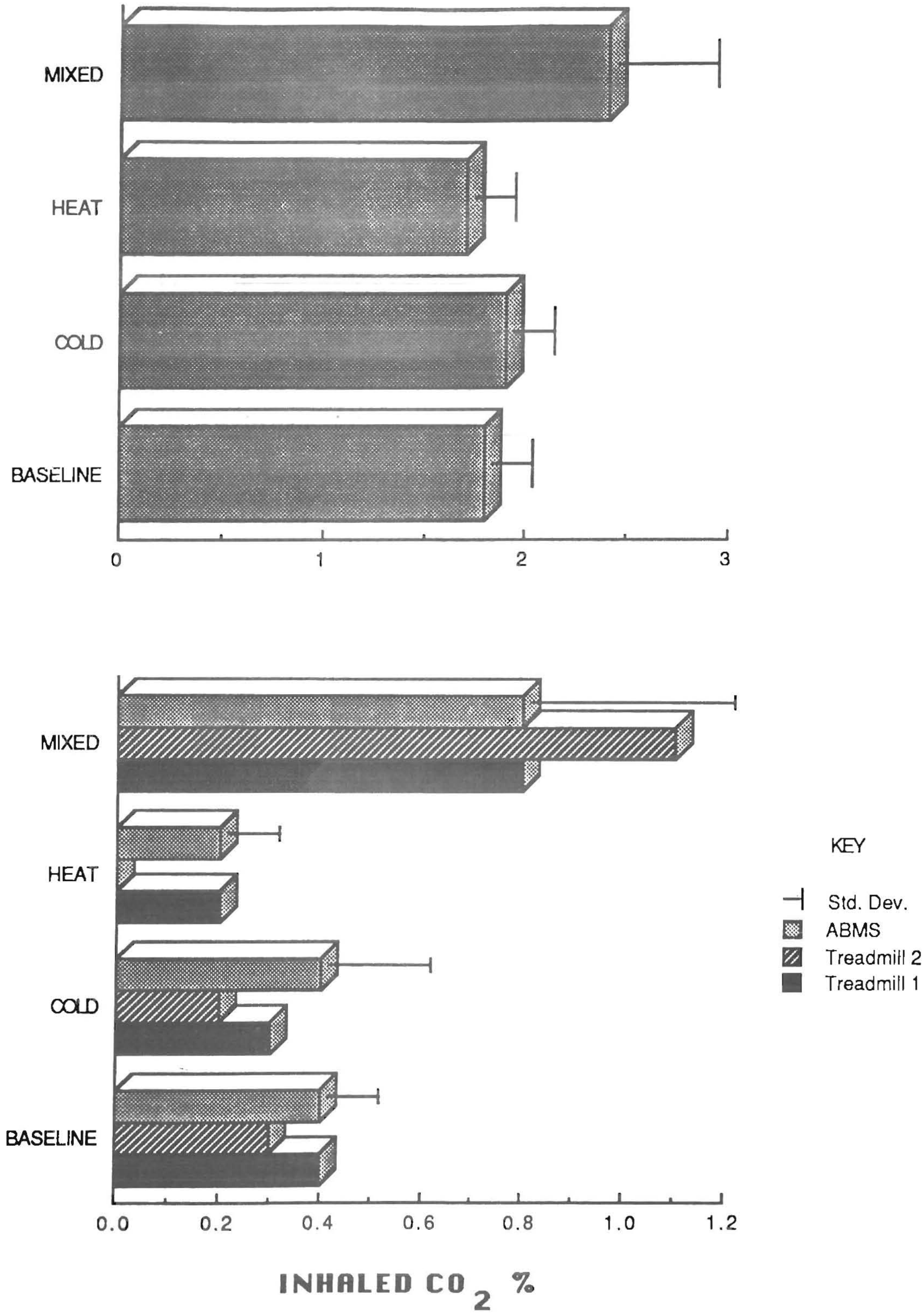

Figure 7.—Average (top) and minimum (bottom) inhaled CO_2.

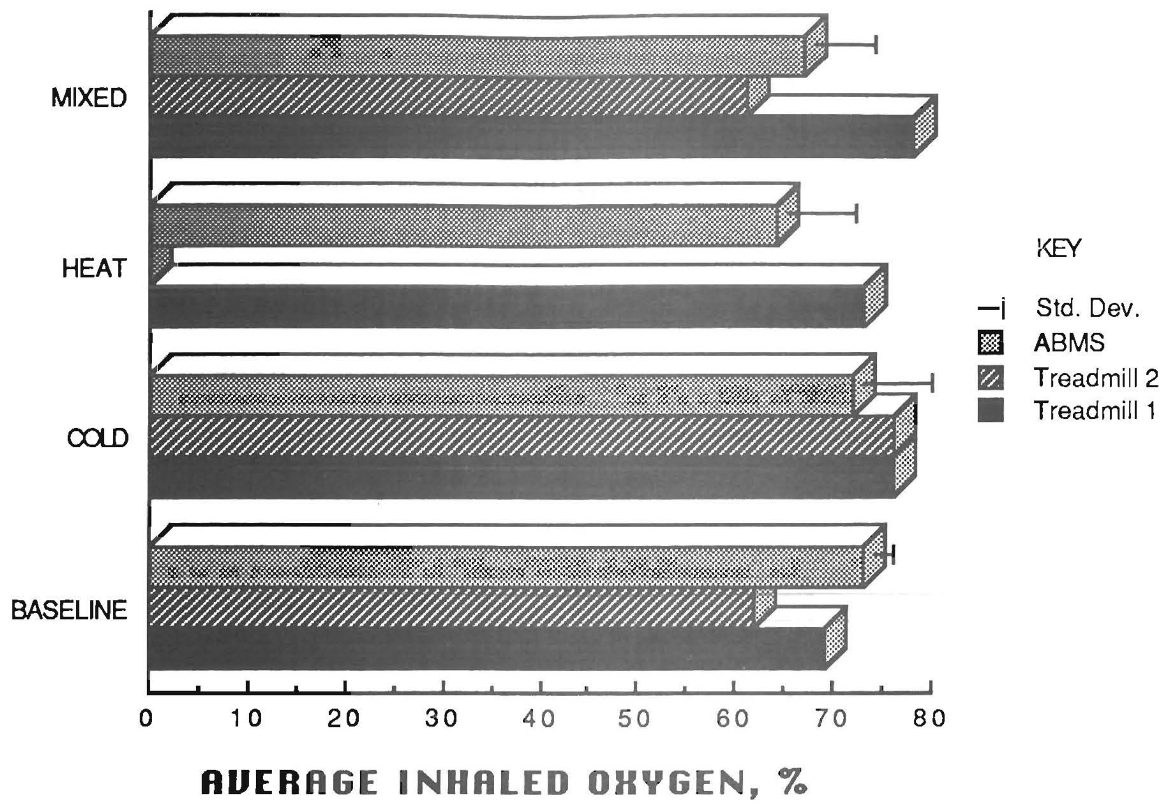

Figure 8.—Average Inhaled O_2.

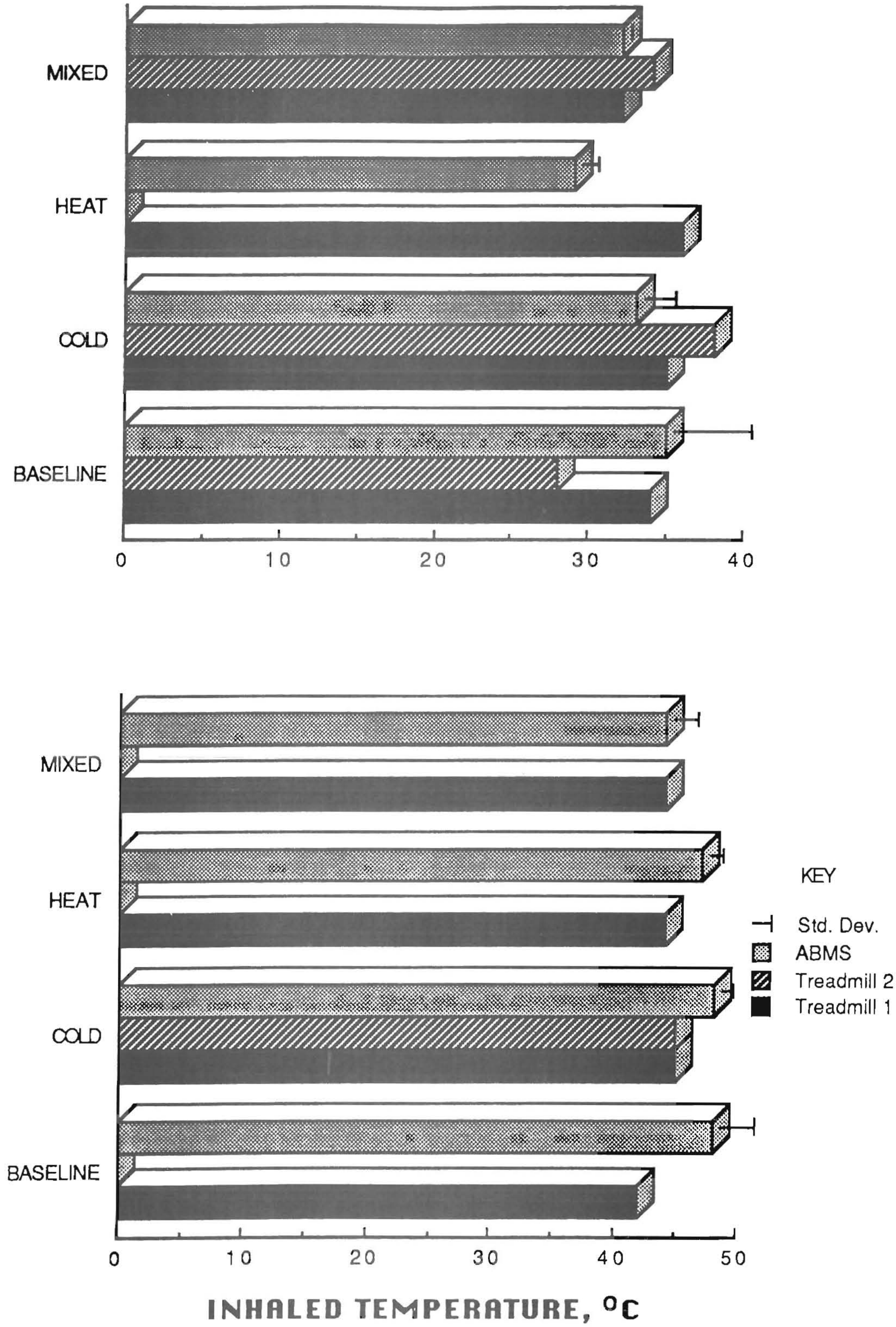

Figure 9.—Wet-bulb (top) and dry-bulb (bottom) temperatures.

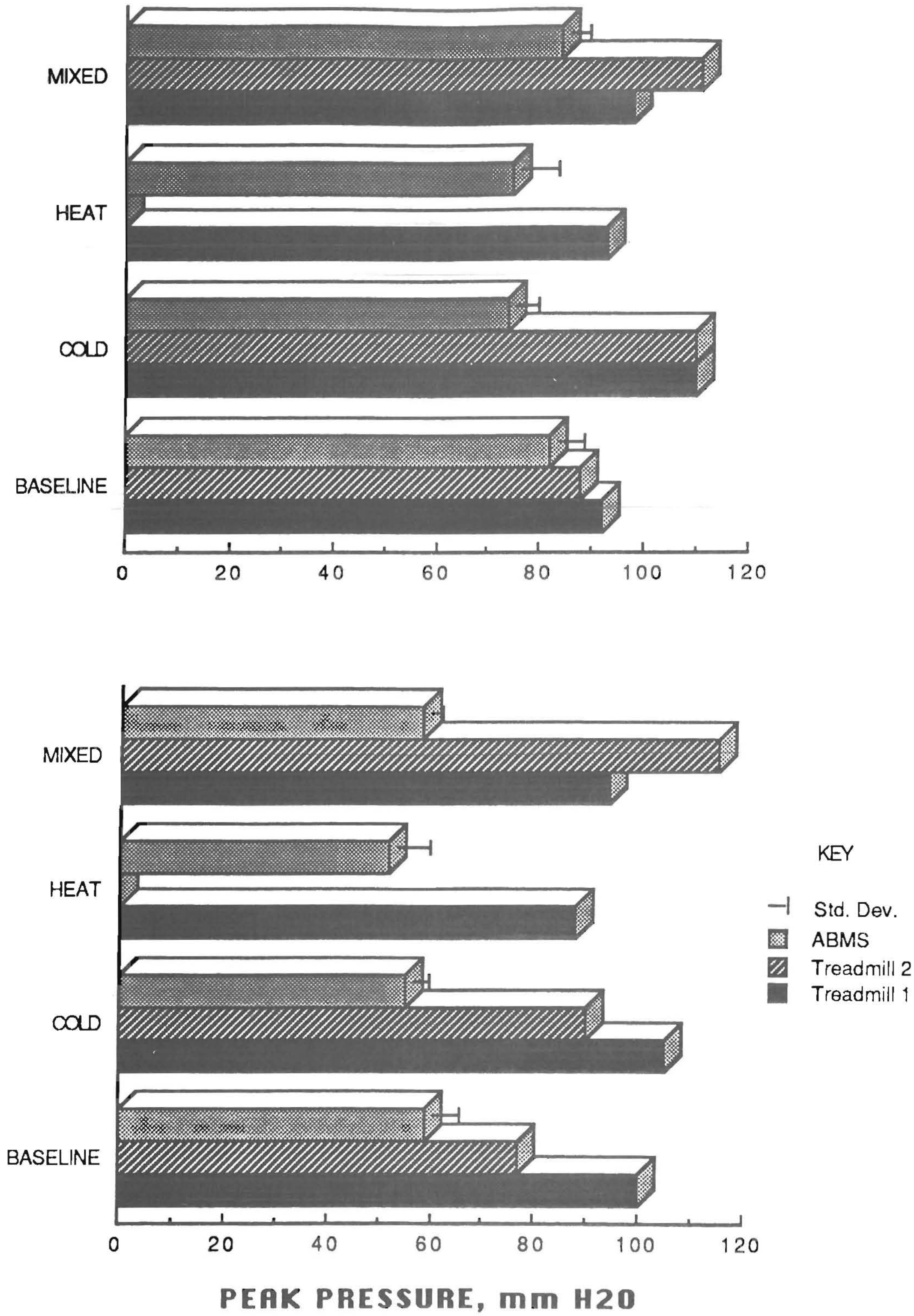

Figure 10.—Peak inhalation (top) and exhalation (bottom) pressures.

noted in the apparatus with combined treatments compared with untreated or singly treated apparatus. The higher CO_2 levels may be due to either the drop and vibration treatment or to the effect of the combination of treatments. In addition, CSE Corp. informed the Bureau that one batch of KO_2 used in the manufacture of the SR-100's had been compromised by exposure to ambient gas, with the result being higher CO_2 levels. That batch was not traceable to individual apparatus, unfortunately. Whatever the cause, the higher levels were within safe limits.

One apparatus suffered a torn bag of desiccant, which spilled its contents, lodging in the relief valve and compromising its seal, leaking ambient gas into the breathing bag upon inhalation.

GENERAL OBSERVATIONS

Several units did not have oxygen in the starter bottles requiring cold starts. In one heat-treated unit to be treadmill tested, the human test subject chose not to continue when the oxygen level fell below 16%. It was later determined that the burst disk was defective and that the venting of the oxygen was not a result of the heat treatment. Heat treating did seem to have an effect on the chemical bed, however. The chemical reaction was slower to start in heat-treated units, imperceptibly in units with starter oxygen, but more noticeably in cold starts. CSE Corp. has determined that heating the chemical bed higher than approximately 90° C negatively affects the reactivity of the chemical. Above 120° C, the bed reaction cannot be started manually before oxygen falls to irrespirable levels.

CONCLUSIONS

Laboratory environmental testing of the SR-100 has uncovered a manufacturing defect in the burst disk of the oxygen starter bottle and a design problem with the desiccant bag. Both of these problems have been corrected by the manufacturer. In addition, testing has revealed a small negative change in reactivity of the chemical bed when heat treated. This is of no importance to the user, but does have some significance to the manufacturer in further understanding of the bed chemistry.

Higher than normal CO_2 levels in apparatus subjected to combine treatments may be the result of the combined effect, the vibration and drop treatment alone, or simply a bad batch of KO_2. In any case, the higher levels were still within safe limits.

In general, the concerns relevant to the first generation of SCSR's also apply to the SR-100. Except for manufacturing defects, the internal condition of the apparatus can be determined by examining the external condition. The major problem is predicted to be not with the apparatus, but with training the user to inspect properly the apparatus.

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